

FUEL CELL CONTROL SYSTEM

BACKGROUND OF THE INVENTION

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1. Field of the Invention

The present invention relates to a system for controlling a fuel cell which generates an electric power by an electrochemical reaction of hydrogen and oxygen and is
10 applied to a family use generator, portable generator and mobile generators for an automobile and ship.

2. Description of the Related Art

The output of the fuel cell is lowered by a supply shortage of hydrogen and /or oxygen, by a blockade of a fuel
15 (hydrogen) line and/or air (oxygen) line due to water flooding, or by a lowering of electrical conductivity of an electrolyte film due to its drying. Further, the fuel cell is degraded and its reliability is lowered, if it is operated under the above mentioned bad conditions.

20 Although its reliability is improved due to margins of operational conditions, its operational efficiency is lowered by excessive supply of hydrogen and oxygen or water.

Therefore, in JP2000-208161A, such a parameter as fuel gas supply is controlled in order to hold a standard
25 deviation of the fuel cell output voltage within a prescribed range.

However, the fuel cell as disclosed in JP2000-208161A has a disadvantage that factors causing the output

deviation are not clearly decided. Accordingly, irrelevant factors are unnecessarily controlled, thereby lowering the operational efficiency of the fuel cell system.

Further, in JP2002-164065A, a cooling water flow direction is switched, thereby forming a prescribed humidity distribution along the built-up direction of individual cells and diagnosing the humidity condition of the fuel cell on the basis of the output voltages of the individual cells. Here, it is assumed that the relative humidity is the highest at the cooling water entrance, while it is the lowest at the exit, because the cooling water temperature is the lowest at the entrance, while it is the highest at the exit.

However, the cell temperature is in general higher at an intermediate portion of the cell than at the cooling water exit. This is because heat is radiated through cell container, while heat radiation is not easily caused at the intermediate portion. Further, the temperature distribution in the fuel cell is diversified by various conditions such as a cooling water temperature, ambient temperature and generated electric power.

Therefore, the fuel cell as disclosed in JP2002-164065A has a disadvantage that the inside humidity is not precisely determined, because the cooling water temperature does not always become highest at the cooling water exit.

SUMMARY OF THE INVENTION

An object of the present invention is to precisely estimate factors causing the output voltage changes of a fuel cell stack, regardless of the internal temperature distribution of a fuel cell.

The fuel cell operation as a whole is precisely diagnosed on the basis of the output voltages of every individual cell or a part of individual cells constructing the fuel cell stack.

It is a concrete object to precisely diagnose and suitably operate the fuel cell stack on the basis of an average output voltage V_a of the individual cells, their standard deviation σ , their individual output voltages, their variance σ^2 of vibration components of the output voltages, their voltage drop speeds of their non-vibration components.

It is another concrete object to precisely diagnose and suitably operate the fuel cell stack, without introducing any uncertain and hypothetical temperature distribution in the fuel cell stack, but on the basis of the output voltages of the highest and lowest temperature cells.

The fuel cell control system of the present invention comprises: a fuel cell stack for generating an electric power by utilizing an electrochemical reaction of hydrogen and oxygen. The fuel cell stack supplies an electric load or a not-shown secondary battery with an electric power. For example, an electric motor for driving the electric vehicle corresponds to the load. The individual cell is, e.g., a solid

polymer electrolyte fuel cell. The output voltage and temperature of each individual cell, or a part of them is measured by a cell monitor.

Further, the measurement result is inputted into an
5 electronic control unit (ECU) for controlling fuel (hydrogen) pump & valve, air (oxygen) pump & valve, humidifier for electrolytes and electric load such as a motor.

According to the present invention, the fuel cell stack
is reasonably and efficiently controlled by diagnosis means
10 (ECU) on the basis of the output voltages and
temperatures of individual fuel cells and their actual and
statistical changes.

BRIEF EXPLANATION OF THE DRAWINGS

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FIG. 1 is a block diagram of the fuel cell control system
of the present invention for, e.g., an electric vehicle.

FIG. 2 is a flow chart, in accordance with Embodiment
1 of the present invention, of the electronic control unit
20 (ECU) operation for diagnosing the fuel cell on the basis of
an average output and so on.

FIG. 3 is a graph showing such an FC state at S109 in
accordance with Embodiment 1 that the average voltage V_a
is normal but an output voltage of an individual cell is out
25 of a prescribed range ($V_a - c \sigma$).

FIG. 4 is a graph showing such an FC state at S111 in
accordance with Embodiment 1 that the average voltage V_a
is lowered from an optimum time average voltage V_0 but

the standard deviation σ is within a normal range.

FIG. 5 is a flow chart for the ECU operation in accordance with Embodiment 2 for diagnosing the fuel cell stack (FC) on the basis of an output change with the
5 passage of time.

FIG. 6 is a graph of an exemplary output voltage change of a certain individual cell, where the solid line is an actual change, the vibration component is a voltage change gap between successive measurements and the non-
10 vibration component is shown by a smoothed curve shown by the dotted line.

FIG. 7 shows an example of the FC built up by eleven individual cells in accordance with Embodiment 3, wherein, for example, the cooling water flows into the cell No. 1 and
15 flows out from the cell No. 11 and temperature measuring means 50 is provided for all individual cells.

FIG. 8 is a graph showing a statistically estimated or averaged relation between the output voltage and temperature, when the absolute humidity at the individual
20 cell is constant, in accordance with Embodiment 3.

FIG. 9 is a graph showing a relation between the output voltages and temperatures of the individual cells, when the water supply is insufficient, in accordance with Embodiment 3.

25 FIG. 10 is a graph showing a relation between the output voltages and temperatures of the individual cells, when the water supply is excessive, in accordance with Embodiment 3.

FIG. 11 is a flow chart of the ECU operation for diagnosing the FC on the basis of the output voltages $V_{t\max}$ and $V_{t\min}$ of the highest and lowest temperature cells, respectively, in accordance with Embodiment 3.

5 FIG. 12 shows an example of an arrangement of the temperature measuring means provided every three individual cells, in accordance with Embodiment 4.

10 FIG. 13 shows an example of temperature interpolation for selecting the highest and lowest temperature cells, in accordance with Embodiment 4.

15 FIG. 14 is a flow chart of the ECU operation, in accordance with Embodiment 5, for diagnosing the FC on the basis of the highest temperature cell only, noticing that the water supply is apt to become insufficient for the highest temperature cell and that every individual cell is supplied with sufficient water, if the highest temperature cell is supplied with sufficient water.

PREFERRED EMBODIMENT OF THE INVENTION

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Preferred embodiments of the present invention are explained, referring to the drawings.

Embodiment 1

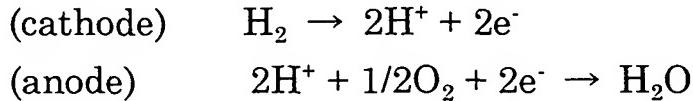
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FIG. 1 is a block diagram of the fuel cell control system for, e.g., an electric vehicle.

As shown in FIG. 1, the fuel cell control system of the

present invention comprises: a fuel cell stack (FC) 10 for generating an electric power by utilizing an electrochemical reaction of hydrogen and oxygen. The FC 10 supplies an electric load 11 or a not-shown secondary battery with an electric power. For example, an electric motor for driving the electric vehicle corresponds to the load 11.

The individual fuel cells are, e.g., solid polymer electrolyte fuel cells. They are piled up and are electrically connected in series with each other. The following electrochemical reaction is caused in the FC 10.



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Further, output voltages of the individual cells measured by a cell monitor 12 (voltage measuring means) is inputted into a control unit 40.

Further, the FC 10 is provided with an air line 20 for supplying the anode (air electrode) with air (oxygen: oxidizing gas) and is provided with a fuel line 30 for supplying the cathode (fuel electrode) with hydrogen.

The the air line 20 is connected with an air pump 21 for pumping air from the outside atmosphere to the FC 10. 25 Further, a humidifier 22 is provided between the air pump 21 and the FC 10. Further, an air valve 23 for adjusting a pressure of the supplied air at the downstream side of the FC 10.

The uppermost stream side of the fuel line 30 is provided with a hydrogen cylinder 31, while a hydrogen valve 32 for adjusting a hydrogen pressure is provided between the hydrogen cylinder 31 and the FC 10.

5 The fuel line 30 is a loop closed at the downstream of the hydrogen valve 32, thereby recovering and circulating the hydrogen inside the fuel line 30. Further, there is provided at the downstream of the FC 10 in the fuel line 30 a hydrogen pump 33.

10 Electronic control unit (ECU) 40 (diagnostic means) comprises: a micro-computer including CPU, ROM & RAM and its peripheral circuits. The ECU 40 receives the output voltages of the individual cells from the cell monitor 12 and outputs control signals to the air pump 21, 15 humidifier 22, air valve 23 and hydrogen valve 33.

The electric power supplied to the load 11 is controlled in such a manner that air and hydrogen supplies are simultaneously controlled by changing rotations of the air pump 21 and hydrogen pump 33, respectively. 20 Particularly, the air supply is set up so as not to cause any deviation go out from a prescribed range in the out put voltage of the FC 10.

FIG. 2 is a flow chart of the operation of the ECU 40 for diagnosing the operation of the FC 10.

25 First, at S101, An electric current in the FC 10 is measured. Then, the following first and third ranges are decided on the basis of the measured electric current, where the first range is a range for determining whether

the average cell voltage V_a is within a normal range and the third range is a range for determining whether the standard deviation σ of the output voltages of the individual cells constructing the FC 10 is within a normal range.

Then, the individual output voltages are measured at S102; the average output voltage V_a is calculated at S103 on the basis of the individual voltages measured at S102; and the standard deviation σ is calculated at S104 on the basis of the individual voltages measured at S102.

If V_a is determined to be within the first range at S105 (YES), S106 follows.

At S106, the cell output voltage of each cell is compared with a second range defined by $(V_a - c \sigma)$, where "c" is a constant. If it is determined at S106 (YES) that there is not any voltage outside the second range among the measured voltages, then, S107 follows.

At S107, it is determined that the FC 10 is diagnosed to be suitably operated, because V_a is normal and moreover the voltage deviation is small. Therefore, the diagnosis result is stored in S108.

On the other hand, If the determination result is YES at S106, S109 follows. FIG. 3 shows an example of the output voltages of the individual cells at S109. V_0 as shown by the solid line is an optimum average output voltage, when the electrolyte film is optimumly humidified. At S109, the FC 10 is being operated in such a manner that V_a is normal and near V_0 , although the output voltage of a

part of individual cells is not within the second range of ($V_a - c\sigma$) and abnormally low, as exemplarily shown in FIG. 3.

In general, if the solid electrolyte film for conduction the hydrogen ion is sufficiently humidified, V_a is not apt 5 to be lowered. Further, if water blocks the fuel electrode of a certain cell, the hydrogen distribution is deviated, thereby causing a drastic output lowering of that certain cell. Therefore, at S109, it is diagnosed that the water in the fuel line 30 is excessively supplied. Then, the 10 diagnosis result is stored at S108.

The excessive water supply is avoided by raising the hydrogen pressure by the hydrogen valve 32, thereby exhausting the water in the fuel line 30 through the solid electrolyte film to the air line 20.

15 Further, if the determination result is NO at S105, S110 follows wherein it is determined whether or not σ is within the third range. If σ is determined to be within the third range at S110 (YES), S111 follows.

As shown in FIG. 4, V_a is greatly lowered from V_0 and 20 is not within the first range, although σ is normal.

In general, the output voltages of the individual cells are not so much changed, if dry air is supplied. This is because the water is hardly condensed in the individual cells. However, V_a is greatly lowered due to the drying in 25 the solid electrolyte films of all the individual cells. Further, if dry air is supplied, water hardly blocks the fuel line 30 and therefore, the hydrogen distribution is not hardly deviated, thereby converging the hydrogen

distribution deviation within a prescribed range. Therefore, it is diagnosed that the electrolyte film is dried. The diagnosis result is stored at S108.

The electrolyte drying is avoided by humidifying the
5 air by the humidifier 22.

Further, If the determination result is NO at S110,
S112 follows. In this case, both V_a and σ are not
abnormal.

In general, if the hydrogen supply is insufficient, V_a is
10 greatly lowered and σ itself is amplified due to the great
deviation of the hydrogen distribution. Therefore, it is
diagnosed that the hydrogen supply is in short. The
diagnosis result is stored at S108.

The hydrogen supply shortage is avoided by increasing
15 the hydrogen supply by raising the rotation number of the
hydrogen pump 33.

According to Embodiment 1, the factors causing the
output change of the FC 10 is precisely estimated on the
basis of the average voltage, voltage deviation and output
20 voltage.

Although in the above explanation the third range was
decided on the basis of the operation electric current of the
FC 10, it may be decided on the basis of σ calculated by
the individual output voltages.

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Embodiment 2

FIG. 5 is a flow chart for the ECU 40 which diagnoses

the FC 10 on the basis of an output change with the passage of time.

- First, at S201, an electric current of The FC 10 is measured, and three values are decided: a fourth range; 5 fifth range; and a prescribed output voltage drop speed of the non-vibration component of each individual cell, where the forth range is a range for determining whether a variance σ^2 of vibration components as explained later is within a normal range, the fifth range is a range for 10 determining whether a non-vibration component as explained later is within a normal range and the prescribed output voltage drop speed is a voltage for determining whether the voltage drop is within a normal range.
- 15 At S202, output voltages of the individual cells are measured. Then, at S203, a hysteresis or change in time of the voltage measured at S202 and stored in a memory in the ECU 40 is read out.

At S204, the output voltage hysteresis for each 20 individual cell is separated into the vibration component and non-vibration component. FIG. 6 is a graph of an exemplary output voltage hysteresis of a certain individual cell, where the solid line is an actual hysteresis, the vibration component is a voltage gap between the 25 successive measurements and the non-vibration component is shown by a smoothed curve shown by the dotted line.

At S205, a variance σ^2 of the vibration components is

calculated. Then, if the non-vibration component is within the fifth range at S206 (YES), S207 follows.

At S207, it is diagnosed that the FC 10 is suitably operated, because the non-vibration component was 5 determined to be within a normal range. The diagnoses result is stored at S 208.

On the contrary, if the non-vibration component is not within the fifth range at S206 (NO), S209 follows, thereby determining whether the non-vibration component is 10 ascending. If the non-vibration component is ascending at S209 (YES), then, S210 follows. At S210, it is diagnosed that the FC is suitably operated. The diagnosis result is stored at S208.

On the contrary, if the non-vibration component is not 15 ascending at S209 (NO), S211 follows, thereby determining whether the voltage drop is within a normal range. If the voltage drop speed is greater than the prescribed value at S211 (YES), then, S212 follows. At S212, it is diagnosed that the hydrogen supply becomes insufficient. The 20 diagnosis result is stored at S208.

On the contrary, if voltage drop speed is not greater than the prescribed value at S211 (NO), S213 follows, thereby determining whether the variance σ^2 of the vibration components is within the fourth range. If σ^2 25 is within the fourth range at S213 (YES), then, S214 follows.

When the non-vibration component falls slowly and more-over σ^2 is small, it means, in general, that the

water in the FC 10 are being increased. This is because an effective reaction surface is decreased, as the water is increased, thereby gradually decreasing the output voltage from every individual cell. Therefore, at S214, it is
5 diagnosed that the water supply becomes excessive. The diagnosis result is stored at S208.

On the contrary, if σ^2 is not within the fourth range at S213 (NO), S215 follows.

When the non-vibration component falls slowly and
10 more-over σ^2 is great, it means, in general, that the solid electrolyte film is being dried. This is because the output voltage falls down gradually, as the solid electrolyte film is dried and the output change becomes great due to a water-absorption and dehydration to and from the electrolyte film.
15 Therefore, it is diagnosed that the electrolyte film becomes dried. The diagnosis result is stored at S208.

According to Embodiment 2, the factors of the output change of the FC 10 is precisely estimated on the basis of the output voltage change in time.

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Embodiment 3

The FC 10 is diagnosed on the basis of the output voltages of the highest and lowest temperature cells. The
25 fuel cell control system is the same as that in Embodiment 1, except that the temperatures as well as the output voltages of the individual cells are inputted through the cell monitor 12 into the ECU 40.

For example, as shown in FIG. 7, eleven individual cells 1 to 11 are built up in the fuel cell (FC) 10, wherein the cooling water flows into the individual cell 1 and flows out of the individual cell 11 and temperature measuring means (temperature sensors) 50 are provided for all individual cells.

The oxygen gas is supplied through the humidifier 22 to the FC 10. Accordingly, the absolute humidity of the oxygen gas is the same at the entrance of every individual cell. Nevertheless, the water supply becomes excessive due to a low temperature in the FC 10, while it becomes insufficient due to a high temperature in the FC 10. Thus, the operation of the FC 10 becomes changed due to its temperature. Reversely saying, it can be diagnosed whether the water supply is excessive or sufficient on the basis of statistically estimated or averaged relations between the individual output voltages and temperatures.

FIG. 8 is a graph showing a relation between the output voltage and temperature, when the absolute humidity at the entrance of the individual cell is constant. As shown in FIG. 8, the output voltage is lowered, both when the temperature is lowered and the water in the gas becomes excessive, and when the temperature is raised and the water becomes insufficient. In other words, the water supply becomes excessive due to lowered output voltage and lowered temperature, while the water supply becomes insufficient due to the lowered output voltage and raised temperature.

Further, FIG. 9 is a graph of the output voltages and temperatures of the individual cells, when the water supply is insufficient. The individual cells which become hot and dried lower their output voltages.

- 5 FIG. 10 is a graph of the output voltages and temperatures of the individual cells, when the water supply is excessive. A large quantity of water becomes condensed at the entrance of the low temperature cooling water, thereby lowering the output voltages near the
10 entrance.

FIG. 11 is a flow chart of the operation of the ECU 40 for diagnosing the operation of the FC 10.

- First, at S301, An electric current in the FC 10 is measured. Then, the temperatures of the individual cells
15 are measured at S302; the highest temperature cell is selected at S303; and the lowest temperature cell is selected at S304.

- Further, the high temperature cell voltage (output voltage V_{tmax} of the highest temperature cell) is measured at S305, and the low temperature cell voltage (output voltage V_{tmin} of the lowest temperature cell) is measured at S306.

- If V_{tmax} is determined to be not greater than V_{tmin} at S310 (NO), an output voltage of the highest temperature
25 cell at its optimum water supply is estimated to be V_{esh} at S311 on the basis of a characteristic map of statistically estimated or averaged temperature-current-voltage relations stored in the ECU 40.

If $(V_{tmax} - V_{esh})$ is determined to be smaller than a prescribed voltage V_{psh} (negative value itself) at S320 (YES), V_{tmax} is lowered. Therefore, it is diagnosed at S321 that the electrolyte is dried due to an insufficient water supply. This is because the hot cells become dried and extremely lower their output voltages, as shown in FIG. 9. On the contrary, if $(V_{tmax} - V_{esh})$ is determined to be not smaller than a prescribed voltage V_{psh} at S320 (NO), V_{tmax} is not lowered. Therefore, it is diagnosed at S322 that the water supply is reasonable.

Back to S310, if V_{tmax} is greater than V_{tmin} at S310 (YES), an output voltage of the lowest temperature cell at its optimum water supply is estimated to be V_{esl} at S312 on the basis of a characteristic map of statistically estimated or averaged temperature-current-voltage relations stored in the ECU 40.

If $(V_{tmin} - V_{esl})$ is determined to be smaller than a prescribed voltage V_{psl} (negative value itself) at S330 (YES), V_{tmin} is lowered. Therefore, it is diagnosed at S331 that a large quantity of water is condensed at low temperature cells and their output voltages are lowered. On the contrary, if $(V_{tmax} - V_{est})$ is determined to be not smaller than a prescribed voltage V_{psl} at S330 (NO), V_{tmax} is not lowered. Therefore, it is diagnosed at S332 that the water supply is reasonable.

When the water supply is diagnosed to be insufficient, the water supply is increased by promoting the water supply to the electrolyte film by increasing the humidifying

power of the humidifier 22 or increasing the air pressure or decreasing the hydrogen pressure. When the water supply is excessive, the humidifier 22 is switched off, the air pressure is decreased or the hydrogen pressure is
5 increased.

According to Embodiment 3, the factors of the output change of the FC 10 is precisely estimated on the basis of the output voltages of the highest and lowest temperature cells.

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Embodiment 4

FIG. 12 shows Embodiment 4. The fuel cell control system is the same as Embodiment 3, except that the
15 temperature sensors 50 are provided, e.g., every three individual cells.

The temperature of the individual cells without the temperature sensor 50 are interpolated, thereby selecting the lowest temperature cell (cell 1) and highest
20 temperature cell (cell 8), as exemplarily shown in FIG. 13.

The highest and lowest temperature cells may be selected among those with the temperature sensor 50.

Embodiment 5

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The FC 10 is controlled on the basis of the highest temperature cell only, noticing that the water supply is apt to become insufficient for the highest temperature cell.

Therefore, every individual cell is supplied with sufficient water, if the highest temperature cell is supplied with sufficient water. The fuel cell control system is the same as Embodiment 3.

- 5 FIG. 14 is a flow chart of the operation of the ECU 40 for diagnosing the operation of the FC 10.

After executing S301 to S306 (the same steps as shown in FIG. 11), $V_{t\max}$ is compared with $V_{t\min}$ at S310 (similarly to FIG. 11).

- 10 If $V_{t\max}$ is determined to be greater than $V_{t\min}$ at S310 (YES), the water supply is estimated to be reasonable or excessive. Therefore, the water supply is decreased at S390, because the individual cells do not instantly become dried, even if the water supply is decreased.

- 15 On the contrary, if $V_{t\max}$ is not greater than $V_{t\min}$ at S310 (NO), the output voltage of the highest temperature cell at its optimum water supply is estimated to be V_{esh} at S311 on the basis of a characteristic map of temperature, current and voltage stored in the ECU 40. Next, ($V_{t\max} - V_{esh}$) is compared with a prescribed voltage V_{psh} (negative value itself) at S320.

- 20 If ($V_{t\max} - V_{esh}$) is smaller than V_{psh} at S320 (YES), it is diagnosed that the highest temperature cell is dried and its output voltage is remarkably lowered. Therefore, 25 the water supply for the FC 10 is increased at S391. On the other hand, if ($V_{t\max} - V_{esh}$) is not smaller than V_{psh} at S320 (NO), the output voltage of the highest temperature cell is not lowered. Therefore, it is diagnosed

that the highest temperature cell is reasonable or excessive. Thus, the water supply for the FC 10 is decreased at S392). and voltage stored in the ECU 40.

The water supply is increased at S391 by promoting
5 the water supply to the electrolyte film by increasing the humidifying power of the humidifier 22 or increasing the air pressure or decreasing the hydrogen pressure. On the other hand, the water supply is decreased at S390 and S392 by stopping the humidifier 22, decreasing the air
10 pressure or increasing the hydrogen pressure.

Modified Embodiments

The output voltage of each cell was detected by the cell
15 monitor 12 in Embodiments 1 to 5. However, the output voltage may be detected every cell group of a plurality of cells.

Further, the hydrogen was circulated in the fuel line
30 in Embodiments 1 to 5. However, the fuel line may be
20 completely opened or closed.